Simulating A Parametric Model of Planetary Atmospheres to Quantify Sustainability Over Time

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Background

Suggested through the **dynamo theory**, some planetary bodies have a core dynamo system which allows the propagation of an external magnetic field and internal heating system [1, 3]. For terrestrial planets, internal heat may also drive the process of **outgassing**, a process in which large quantities of various types of molecules are added to the atmosphere [1].

Through geological activity and an external magnetic field, a planet is often able to generate and *sustain* an atmosphere. The replication of these processes over **geological times** (billions of years) is possible through parametric models.

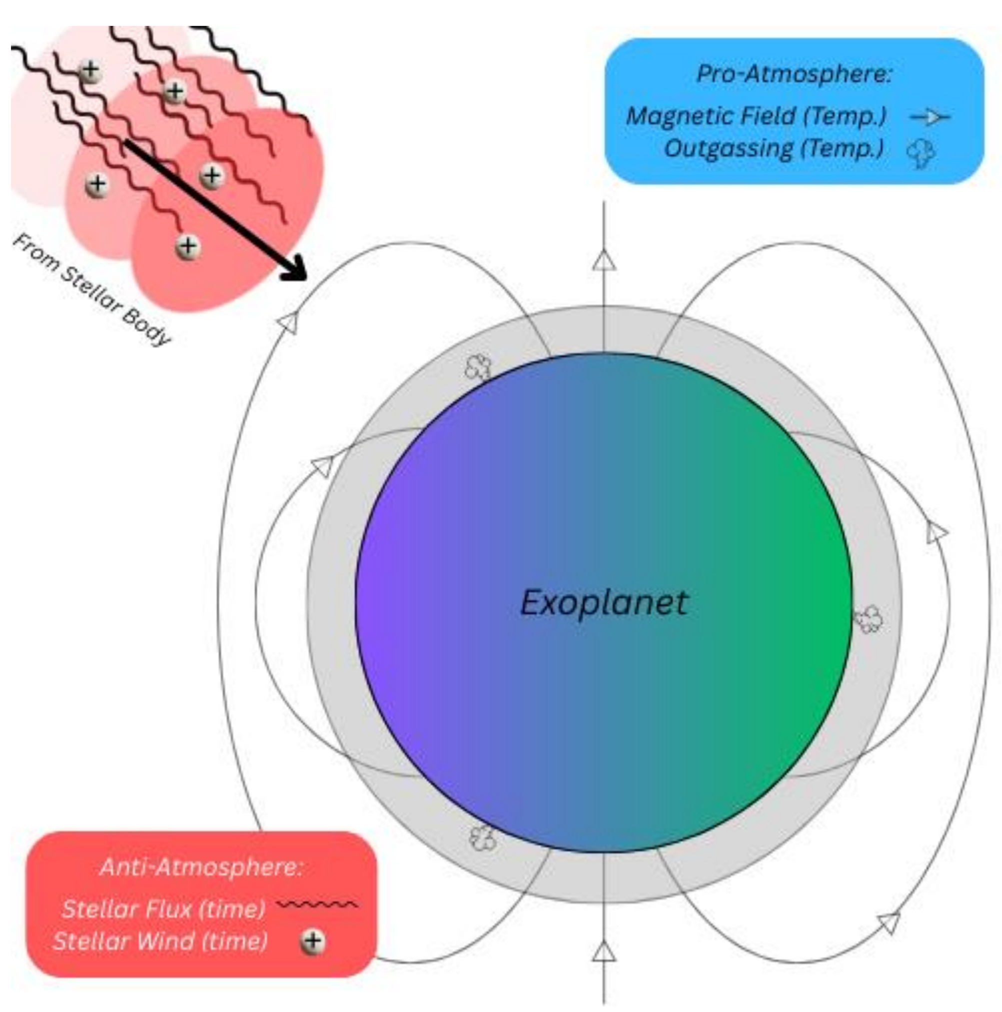

Figure 1: Image not to scale. An exoplanet that has an active dynamo may produce a magnetic field and "outgassing" through volcanic activity. These processes help produce and sustain an atmosphere while UV solar flux and stellar wind stripping degrades an atmosphere.

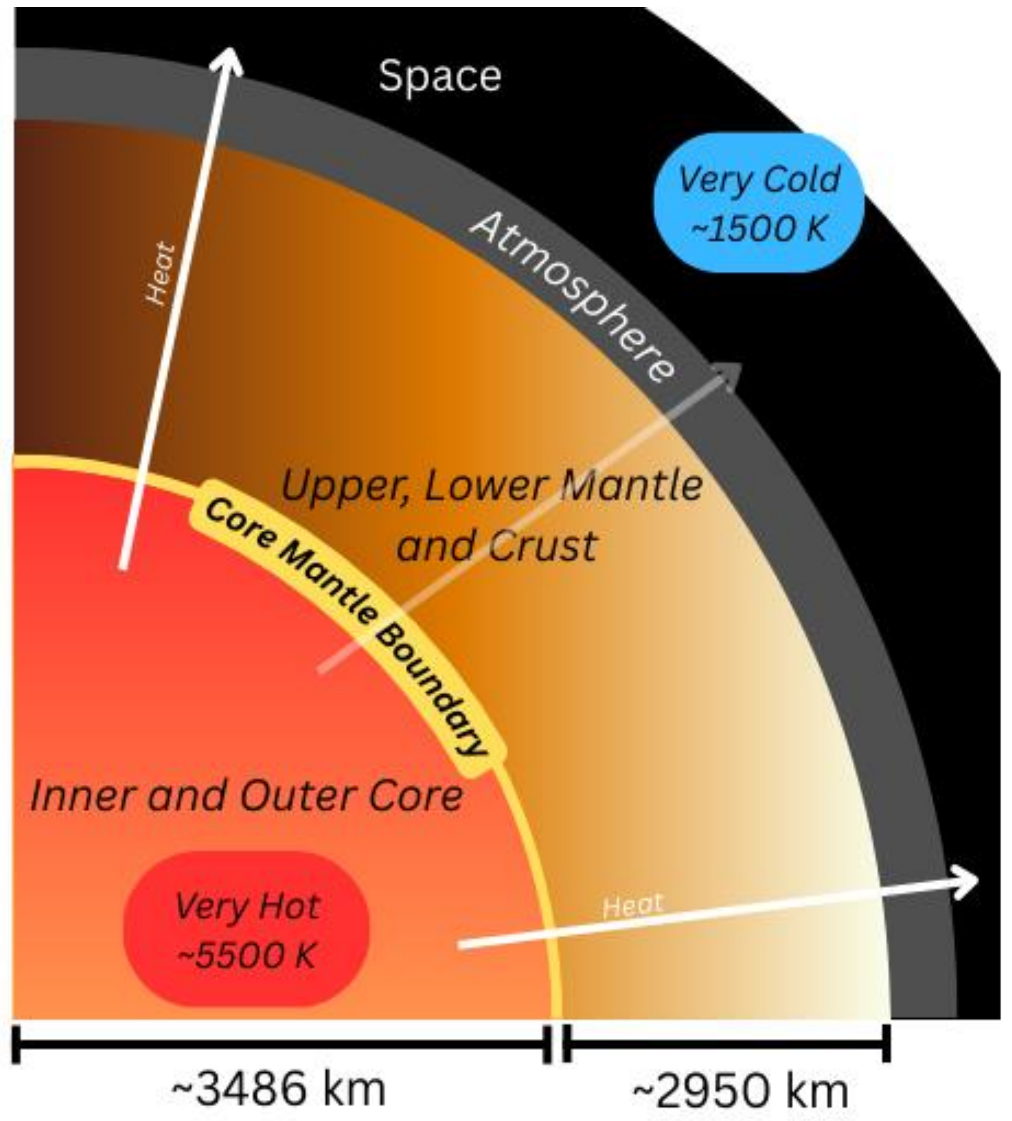

Figure 2: Not to scale. Heat is perpetuated through the internal system of earth mainly through convection currents. However, after billions of years, you can model this heat loss over time with diffusion. The Core-Mantle Boundary is a massive break for heat conduction.

Research Problem & Methodology

While an internal heat model is not new to the field, an extensive model that demonstrates outgassing rate versus depletion rate is a modern idea. The internal heat model was built through a **Python language environment** using numerical integration packages.

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The temperature evolution with time is given by the diffusion equation,

$$\frac{dT}{dt} = \alpha \nabla T = \alpha \frac{dT}{dr} \quad (1)$$

where T is temperature (K), t is time (seconds), α is the diffusion coefficient $(\frac{m^2}{s})$, and r is the radius (m)

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Data & Results

Based on the most substantial example, Earth, the internal heat corresponded correctly as simulated for over **five billion years**.

A corresponding magnetic field was built on the relationship between the heat diffusion across the Core-Mantle Boundary while producing Earth-like results [3, 4].

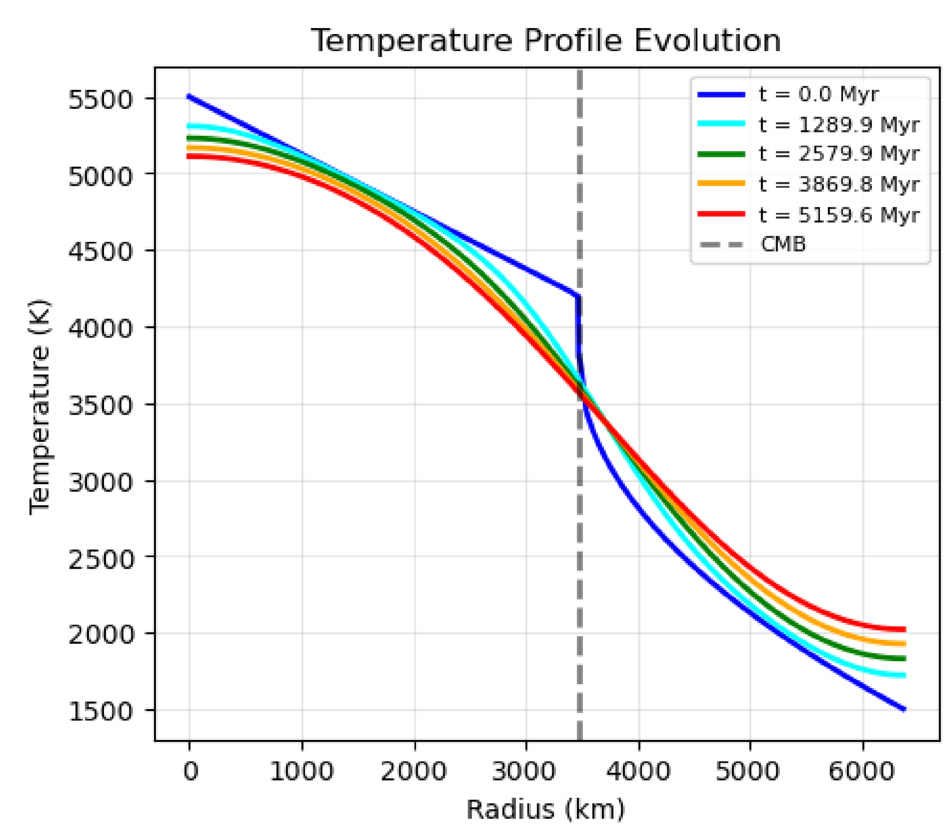


Figure 3: Temperature across Earth's radius over billions of years. Note the sharp decline at the CMB.

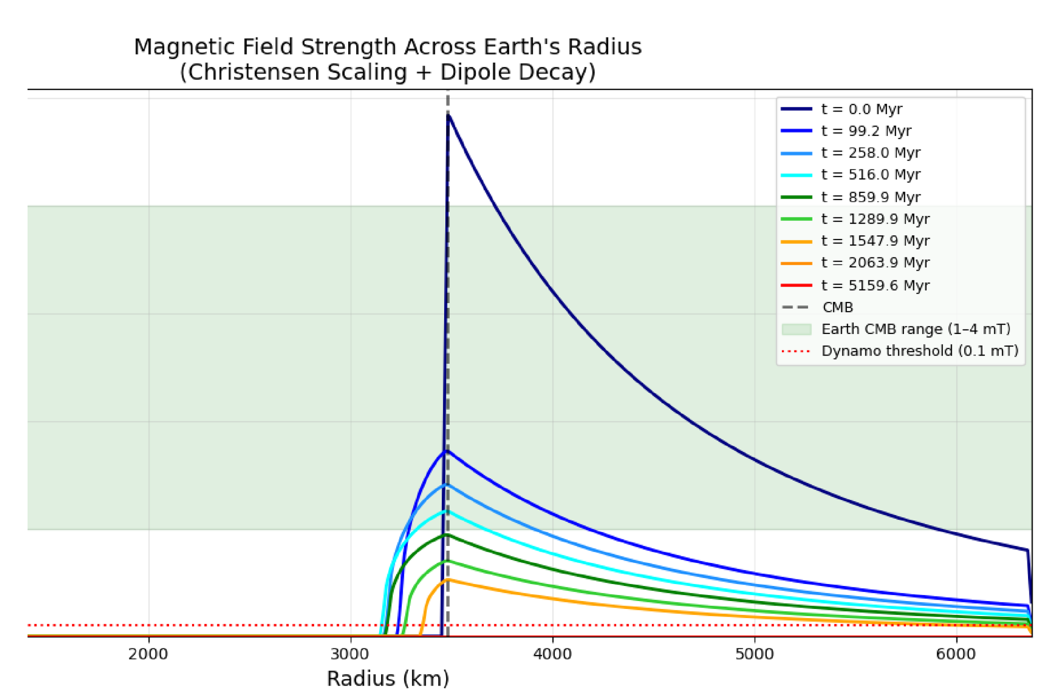


Figure 4: Magnetic Strength as a function of time and temperature across the CMB.

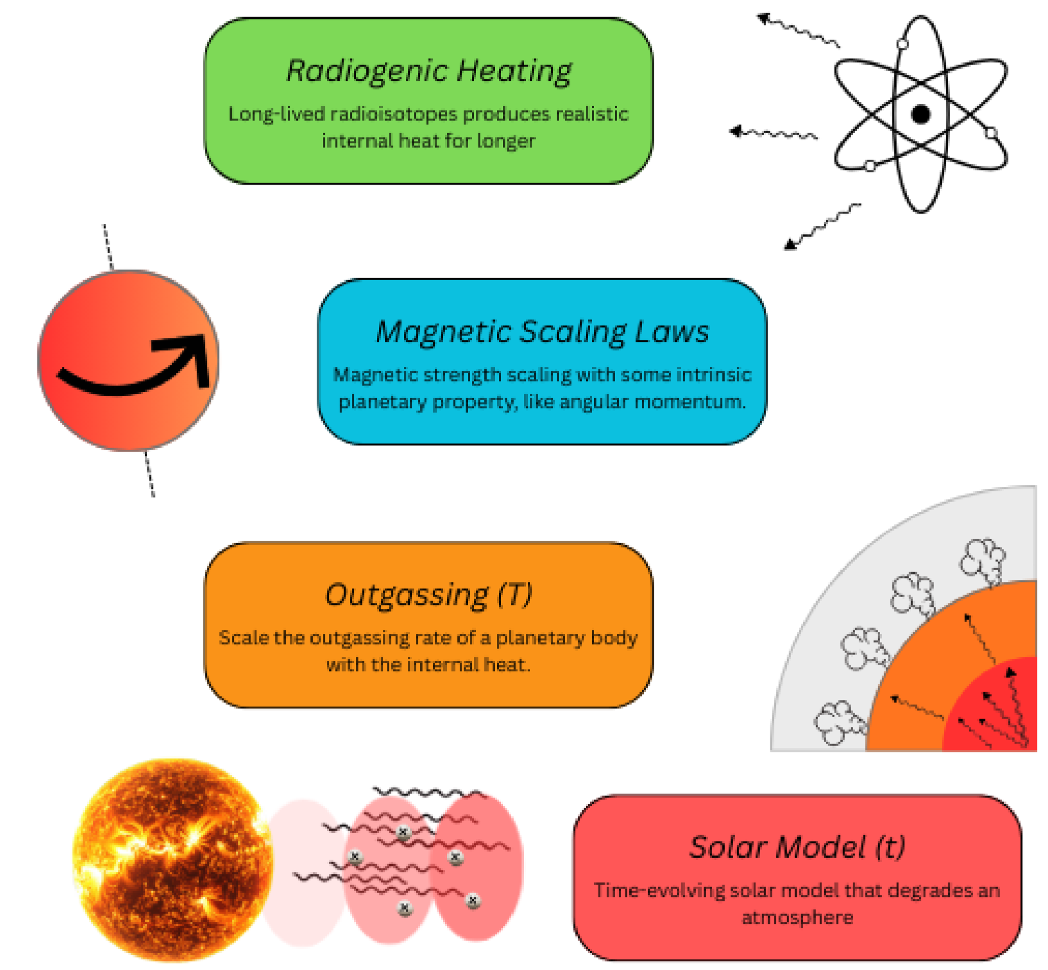


Figure 4: Planned developments of the model. Radiogenic heating and magnetic scaling laws are n schedule to be completed by the end of Mar ch.to be completed by the end of March.

Future Development

Currently developing for this model is the:

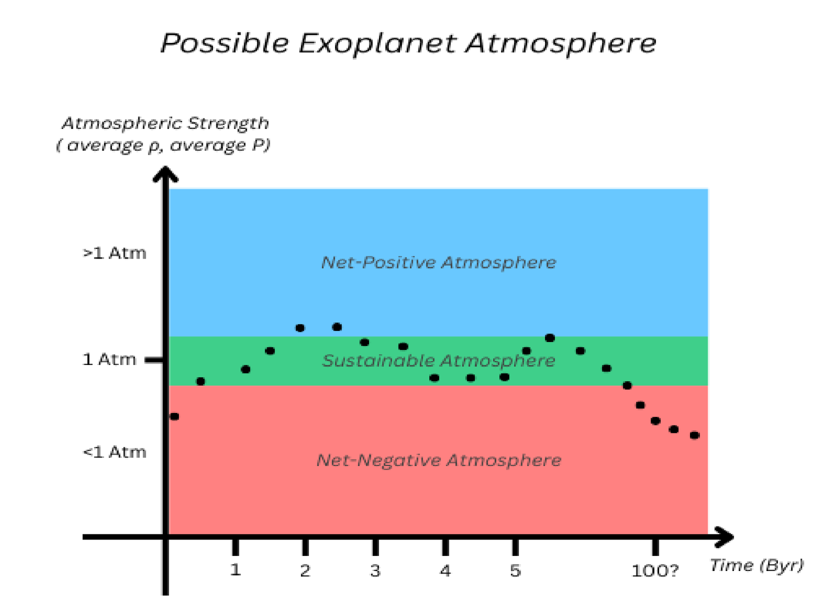
- Realistic radiogenic heating function (Current)
- More magnetic scaling laws (Current)
- Develop the outgassing rate (Future)
- Time-evolving solar flux/wind degeneration model (Future)

The future of this model is to eventually create an open-source, publicly available project for anyone to use and learn. For this, a front-end user interface would be developed.

Implications of Model

The versatility of this model is expected to be extrapolated to the parameters of measured exoplanets, to simulate the **survivability of their atmosphere** under their host star. From this extensive simulation, large telescope missions like **HabEx** or **JWST** can focus on detecting an atmosphere on an exoplanet that is likely to contain it from planetary formation.

Included in the model's versatility, the simulation of Earth's atmosphere gives insight into **climate change** models and the role of outgassing rates over geologic time for a future insight model.



References

[1] M.A.C. Perryman, *The Exoplanet Handbook* (Cambridge University Press. Copyright, Cambridge, 2018).
[2] J.P. Vallée, "Observations of the Magnetic Fields inside and outside the Milky Way, starting with Globules (~ 1 parsec), Filaments, Clouds, Superbubbles, Spiral Arms, Galaxies, Superclusters, and ending with the Cosmological Universe's Background Surface (at ~ 8 Teraparsecs)," Fundamentals of Cosmic Physics **19**, 1–49 (1997).
[3] P. Driscoll, and P. Olson, "Optimal dynamos in the cores of terrestrial exoplanets: Magnetic field generation and detectability," Icarus **213**(1), 12–23 (2011).
[4] C.J. Schrijver, and G.L. Siscoe, *Heliophysics: Evolving Solar Activity and the Climates of Space and Earth* (Cambridge University Press, 2010), p. 208.

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